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16. Abstract

In response to the need for a faster, more economical means of producing land-use maps, this study evaluated the suitability of using ERTS computer compatible tape (CCT) data as a basis for automatic mapping. Significant findings are: (1) automatic classification accuracy greater than 90% is achieved on categories of deep and shallow water, tended grass, rangeland, extractive (bare earth), urban, forest land, and nonforested wet lands; (2) computer-generated print-outs by target class provide a quantitative measure of land-use; and (3) the generation of map overlays showing land-use from ERTS CCTs offers a significant breakthrough in the rate at which land-use maps are generated. Rather than uncorrected classified imagery or computer line printer outputs, the processing results in geometrically-corrected computer-driven pen drawings of land-use categories, drawn on a transparent material at a scale specified by the operator. These map overlays are economically produced and provide an efficient means of rapidly updating maps showing land-use.

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AUTOMATED LAND-USE MAPPING FROM SPACECRAFT DATA

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BIOGRAPHICAL SKETCH

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ABSTRACT

Efficient usage of land is one of the most pressing problems facing our country today. Improper planning of new industrial and residential areas can have disastrous effects on the environment. The land-use map provides information essential to this planning. Present techniques based on the use of aerial photography and photometric mapmaking are mostly manual, expensive, and time-consuming. Although the maps produced are very accurate, in fast growing areas, the maps are out-of-date by the time they are printed.

In response to the need for a faster, more economical means of producing land-use maps, this study evaluated the suitability of using ERTS computer compatible tape (CCT) data as a basis for automatic mapping. Significant findings are (1) automatic classification accuracy greater than 90% is achieved on categories of deep and shallow water, tended grass, rangeland, extractive (bare earth), urban, forest land, and nonforested wet lands; (2) computer-generated printouts by target class provide a quantitative measure of land-use; and (3) the generation of map overlays showing land-use from ERTS CCTs offers a significant breakthrough in the rate at which land-use maps are generated. Rather than uncorrected classified imagery or computer line printer outputs, the processing results in geometrically-corrected computer-driven pen drawings of land-use categories, drawn on a transparent material at a scale specified by the operator. These map overlays are economically produced and provide an efficient means of rapidly updating maps showing land-use.

BACKGROUND

National, state, and local government agencies, as well as conservationists, environmentalists, and private citizens, are becoming increasingly concerned about the utilization of the land of our country.

When used for agriculture, forestry, or rangeland, the land is essentially a renewable resource which can be conserved and used over and over. However, when the land is developed, it is, in effect, consumed except for "redevelopment." Once, development and expansion were viewed with pride by most communities of our nation. Now, it is being realized that uncontrolled development can lead to blight, eyesores, over-development, and eradication of priceless assets that should be passed on. The land was considered inexhaustable in the past; it is now realized that land development must be planned if the conflict between utilization of our resources (including the land) and maintenance of the quality of our lives is to be resolved. The land-use map provides information essential to this planning.

By present techniques, a map is generated in several steps. If a good topographic map of the area does not exist, aerial photography is collected and the topographic map is generated using stereo photography and a stereoplotter or orthoprinter. The land-use information is derived either by photo-interpretation of the photography, by ground survey teams, or by a combination of both. The information is then added to the topographic base to create the desired land-use map. A typical effort of this type was the generation of a land-use map of Oakland County, Michigan, which cost $250, 000 and required two to three years to complete. These photometric mapmaking techniques are accurate but, in high growth areas, the maps produced are usually out-of-date by the time the map is printed.

The need for a faster and more economical means of generating land-use maps has led Bendix (Ref 1)* and a number of other organizations (Ref 2, 3, and 4) into evaluating computer target "spectral recognition" techniques as a basis for automatic target classification and mapping. These classification techniques have been under continued development at Bendix for the past 8 to 10 years, primarily using aircraft multispectral scanner data and, more recently, using ERTS/MSS and Skylab/EREP-S192 data.

To implement these "spectral recognition" techniques with ERTS MSS data, a computer is provided (trained) with samples of ERTS measurements on each land-use category of interest. Each MSS sample (spatial) measurement is composed of a radiance measurement in the four bands. The magnitude and variation of this radiance (proportional to target reflectance), measured as a function of band number (or wavelength), is the target "spectral characteristics" or "signature" which forms the basis for computer recognition. In the "decision processing" mode, the probability of the spectral characteristic arising from each one of the different land-use categories of interest is computed for each spatial resolution element and a decision is reached by the computer as to the most likely target type.

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*References, tables, and illustrations can be found, in that order, at the end of this paper.

Research, to date, in computer spectral recognition techniques has been limited to presenting the interpreted land-use data in the form of "decision or classified imagery", either color-coded on TV or film (Ref 1), in which a color designates a land-use category, or in the form of a line printer output (Ref 1, 2, 3, and 4), in which a computer symbol designates the category.

The land-use information contained within this decision imagery, to be of value for resource management, must still be geometrically-corrected and transformed into a map coordinate system. By present techniques, this is a manual, time-consuming procedure, which has been a stumbling block to automatic map making. The technique reported permits the decision imagery/line printout stage to be bypassed, if desired, thereby permitting significant increases in the rate at which land-use maps can be generated. The procedures are illustrated, using ERTS data acquired in April of 1973 to generate land-use map overlays and data for Oakland County, Michigan.

TEST SITE

The data for this study was selected from the second CCT of ERTS scene 1265-15474, acquired on 14 April 1973, and corresponds to a ground coverage of approximately 1.6×10^3 km^2 (625 square miles) in Southeastern Michigan. It includes most of Oakland County and small portions of Lapeer and Macomb Counties. Oakland County was chosen for the primary test area because it is representative of many counties throughout the country wherein urbanization is occurring at a rapid rate. The county, under growth pressure by both the cities of Pontiac and Detroit, is in a rapid state of transition from rural to urban land-use. Excellent ground truth, in the form of aerial photography, aerial photo-mosaics, and land-use maps of 1966, were available from the office of the Oakland County Planning Commission. The commission, a major user of remote sensing information for county planning purposes, and nationally known as such, had also agreed to evaluate and immediately apply the land-use maps and data resulting from this study, if the data so warranted.

LAND-USE CATEGORIES

To evaluate the practicality of using ERTS data as a basis of automatic mapmaking, the land-use classifications: urban and built-up land, 01; tended grass 01-( ); extractive land, 01-04; rangeland, 03; forest land, 04; deep water, 05-( ); shallow water, 05-( ); and non-forested wetlands, 06 were chosen. The classification numbering, where possible, corresponds directly with those in Table 1 as defined by Geological Survey Circular 671 (Ref 5). Additional categories could have been developed from the April, 1973 tape but the study objective was to evaluate the mapmaking techniques rather than to determine maximum number of categories possible.

One category that could have been classified but wasn't discovered until after the processing had been completed was heavy industrial. This category was found to have spectral characteristics that were very different from those of the urban category used. The urban category, in this case, was composed mostly of commercial and residential areas. Also notable among the classifications are deep and shallow water, tended grass, and rangeland (untended grass). Because of bottom reflection, shallow water has a significantly different reflectance characteristic than deep water (over 8 m deep), forcing it into a separate category. In April, tended grass and rangeland in Michigan also have different reflectance characteristics. Tended grass, a surrogate of urban activity, in most cases were the golf courses and cemeteries, usually quite green and having high reflectance due to heavy fertilization and watering. The rangeland, at this time of the year, is brown. Rangeland and tended grass, and deep and shallow water could, if desired, have been combined to form the categories grass and water, respectively.

A practical consideration in the selection of all categories was the ability to locate, in the ERTS scene, known areas of sufficient size to be spectrally representative of each land-use category. Experience has shown that these "training" areas should be 25 ERTS elements (an element being 79 by 79 m) or larger in size. The spectral data edited from the ERTS CCTs of these areas are used to train the computer to recognize similar spectral land-use categories throughout the CCT.

DATA PROCESSING

Computer software, techniques, and procedures used to transform ERTS CCTs into land-use maps and data were developed in the Bendix Earth Resources Data Center. The elements of this center include a Digital Equipment Corporation PDP-11/15 computer with 32 K-words of core memory, two 1.5 M-word disk packs, two nine-track 800-bit-per-inch tape transports, a line printer, a card reader, and a teletype unit. Other units are a color moving-window computer-refreshed display; a glow-modulator film recorder; and a computer-controlled Gerber plotter.

The data processing steps used to transform ERTS CCTs into land-use map overlays and data are shown in Figure 1. The implementation of these steps and the results achieved are briefly summarized in the following paragraphs.

Locate Training Areas

The first step in the development of the Oakland County land-use map was to locate the CCT coordinates, in terms of resolution element number and scan-line count number, of those areas that best typified the land-use target categories of interest, the "training areas". This function was performed by techniques that included transforming a single channel of data to 70-mm film and to a gray-scaled computer line-printer printout, and by simply viewing data on the color-coded moving-window display. The last technique was found to be the fastest way of locating the training areas. Once the target of interest is located on the display, a computer-generated gray-scale image of the target scene is produced in order to perform detailed editing by scan-line count and resolution element number.

Develop Target Characteristics

Inputting the training area coordinates (boundaries) to the computer permits the ERTS spectral measurements within these boundaries to be extracted (edited) from the CCTs and placed into computer disk files. One file is established for each different land-use category. The data in each file are then processed to obtain a numerical descriptor to represent the spectral characteristics of each land-use category of interest. The descriptors presently include the mean signal and standard deviation for each band and the covariance matrix taken about the origin.

Evaluate Target Characteristics and Classification Techniques

Once the numerical descriptions which define the spectral characteristics of each target category are determined, the operator executes the "canonical analysis" program. This program, previously reported by Dye (Ref 6), derives, for each target category being sought, a set of "canonical coefficients". In the decision processing phase, these coefficients are used by the computer to form a linear combination of the ERTS measurements to produce a "canonical variable" whose amplitude is associated with the probability of the unknown measurement being from the target sought.

In decision processing, the probability of an ERTS measurement arising from each one of the different land-use categories of interest is computed for each ERTS spatial resolution element, and a decision based on these computations is reached. If all probabilities are below a threshold level specified by the operator, the computer is permitted to decide that the target viewed is unknown (an undefined land-use category).

Before producing decision data on a large amount of ERTS data, a number of tests are applied to evaluate the computer's capability of performing the desired target classification. The tests include generating scatter diagrams, generating classification accuracy tables, and viewing the results of processed data on a TV monitor.

The classification accuracy table provides the operator with a quantitative measure of the interpretation accuracy. In this step, the canonical coefficients are used in the decision processing but the data processed is limited to that which is well known, i. e., the training data that was previously edited and stored on the disk file. Processing this data and keeping an accurate record of decisions permits the computer printout shown in Table 2 to be developed. In the table, training set one, tended grass, is classified as tended grass 97% of the time and as rangeland, 3% of the time. Also, target group four, urban areas, as shown in the table, is confused somewhat with extractive (bare earth/concrete), rangeland, and wetlands.

This is logical since the urban area category is made up of these materials. It is also noted here that the classification accuracy for all categories is greater than 90%. This satisfies Anderson's first criteria (Ref 7) for a minimum classification accuracy of 90%.

Produce Decision Data Products

When the investigator is satisfied with the accuracy of the decision processing, the canonical coefficients are placed into the computer disk file and are ready to process the full ERTS CCT or portions of the CCT defined by the investigator. Decision products, produced for this study and illustrated below, included printouts giving the area covered by each land-use category, decision imagery, and decision map overlays.

The canonical coefficients defining each of the eight land-use categories was first applied to classify that portion of the CCT covering Oakland County. This first step in the decision processing resulted in a new or classified CCT, wherein each ERTS spatial element is represented by a code designating one of the eight land-use categories. This first step also results in the computer-generated area measurement table shown in Table 3.

Area Measurement Table - The area measurement table is the first real data product useful to land-use planning. This table provides a quantitative measure of the amount of land that falls within a particular category in terms of square kilometers, acres, and as a percent of the total area processed.

It can be noted in Table 3 that forest land (trees), for example, composed 11% (65, 732 acres) of the total 625-square-nautical-mile (581, 206 acre) area processed. Total surface water (shallow plus deep) covers 10, 099 acres. This printout would be very useful for applications requiring a quantitative measure of land-use within specified political or natural, i. e., watershed boundaries. Obtaining similar printouts from additional ERTS overflights would provide additional land-use categories and establish the dynamics of land use, i. e., how its use changes with time.

The computer classified the Oakland County areas of the ERTS tape into the nine categories of Table 3 at a rate of approximately 130 acres per second. This rate will increase by more than ten times when hardware under development is used to perform the target classification function presently accomplished by computer software algorithms.

Decision Imagery - The classified tape produced from decision processing was also used to generate 70-mm imagery wherein each image shows a single land-use category at a scale of 1:1, 000, 000. This decision or classified imagery is geometrically (spatially) identical to the data on the classified CCT, which, in turn, is identical geometrically to the data on the CCT provided by NASA from which it was produced. Since the NASA tape is from bulk processing

(Ref 8), some geometrical errors exist and are carried over into the decision imagery. Also, the CCT data provided from bulk processing are not corrected for Earth rotation; consequently, the decision imagery will not directly overlay a UTM map coordinate system.

Decision imagery, although not geometrically-correct, is produced rapidly and provides an immediate overview of the processed scene. The imagery is particularly useful for comparing results of decision processing with ground truth to confirm classification accuracy.

Decision imagery of selected land-use categories can also be registered to produce color-coded (or gray-scale-coded) decision imagery where a color (or gray-scale level) denotes a specific land-use category.

Figure 2 shows a composite scene formed from decision imagery of deep and shallow water as mapped from ERTS and compared with aerial photography. Orchard Lake, pictured in this figure, is approximately 3 mi. on each side. Deep water is printed gray and shallow water is printed black. Comparison of deep and shallow waters shown in the aerial photography with the computer interpretations shows the excellent classification accuracy being achieved from the spacecraft data.

Decision May Overlays - To produce land-use classifications that will directly relate to a map, the decision (classified) CCTs are submitted to a second stage of processing. In this stage, a new tape is generated that has data corrected for Earth rotation and that is formatted to be compatible for driving the Gerber plotter. This tape, when played back by the computer, causes a geometrically-corrected map of a specified target class to be drawn on film at a map scale selected by the operator. The operator has an option of obtaining either boundary line drawings which enclose a select land-use category or filled-in boundaries. The film, when removed from the plotter and photographically processed, provides transparent overlays which can be used directly, as those in Figure 3, or processed further to produce color-coded land-use overlays, as those in Figure 4.

Figure 3 shows a map overlay of the boundary lines enclosing deep and shallow water, i.e., total surface water. In the same figure, the water overlay is also shown on an AMS 1:250,000 map. Since difference in land-use showing on the base map and overlay are immediately apparent, the overlay technique is particularly useful for locating changes in land-use and updating base maps.

In Figure 4, the filled-in version of four land-use categories are shown overlaying the AMS 1:250,000 map. These overlays appear very accurate, as shown by the ability of water category to fall within the lake outlines on the maps. Especially notable is the urban category centered over the city of Pontiac, Michigan and the forested land category. Forested land (trees) accurately cover the small island in Orchard Lake. By referring to the aerial photograph in Figure 2, the classification accuracy can be further confirmed.

SUMMARY

Based on the results of this study and similar processing results recently achieved, it is concluded that ERTS-1 MSS data can be used to automatically map Level I and most Level II categories. The studies assessment in regards to ERTS capability for automatically mapping these categories is shown in Table 1. The mapping performance (accuracy, repeatability, etc.) satisfies Anderson's working criteria (Ref 7) at publication scales of 1:250,000 and smaller.

Many overlays were generated from ERTS tapes having scales that ranged from 1:24,000 to 1:1,000,000. The 1:250,000 and smaller scale seems best-suited to ERTS data. At this scale, land-use boundary lines appear smooth and mapping errors are equal to or less than the width of the line used to describe the boundaries. As the map scale approaches 1:24,000, the land-use boundary lines become increasingly rough and mapping errors become more apparent. This was expected since an individual ERTS element is approximately 1/8 in. on a side at 1:24,000. Computer smoothing techniques and the use of data from multiple ERTS overflights should be used to improve the accuracy of locating land-use boundaries at these larger scales.

The automatic spectral processing techniques were found to be very fast. Each resolution element within an ERTS CCT is placed into one of 16 target categories within a few microseconds. The complete CCT (25 by 100 mile area) can be interpreted within minutes, followed immediately by a printout giving area covered by each target class in square kilometers and acres. Computer-generated map overlays were produced within a two to three-day time period. These processing speeds, coupled with the fact that ERTS tapes are relatively inexpensive ($160 per ERTS scene) and available on a routine basis (every 18 days) is believed to provide a significant breakthrough in the art of developing and updating land-use maps.

It is estimated that land-use maps at a scale of 1:250,000 and smaller can be produced at a tenth of the cost of conventional techniques. Land-use maps produced from ERTS data could be produced on a county, state, or regional basis and could be updated anytime a planner deemed necessary. These maps are also sufficiently economical to map areas never before considered for land-use planning, such as deserts, mountainous areas, and the large expanses of Indian reservations.

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Table 1 Automatic Classifications Possible from ERTS

Land-Use Classification System Circular 671		Classification from ERTS-1
Level I	Level II	
01. Urban and Built-up Land		X
	01. Residential	/
	02. Commercial and Services	X
	03. Industrial	X
	04. Extractive	X
	05. Transportation, Communications, and Utilities	X Transportation Only
	06. Institutional	0
	07. Strip and Clustered Settlement	?
	08. Mixed	/
	09. Open and Other	X
02. Agricultural Land		X
	01. Cropland and Pasture	X
	02. Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas	/
	03. Feeding Operations	?
	04. Other	/
03. Rangeland		X
	01. Grass	X
	02. Savannas (Palmetto Prairies)	/
	03. Chaparral	?
	04. Desert Shrub	?
04. Forest Land		X
	01. Deciduous	/
	02. Evergreen (Coniferous and Other)	/
	03. Mixed	X
05. Water		X
	01. Streams and Waterways	/
	02. Lakes	X
	03. Reservoirs	X
	04. Bays and Estuaries	X
	05. Other	X
06. Nonforested Wetland		X
	01. Vegetated	X
	02. Bare	X
07. Barren Land		X
	01. Salt Flats	?
	02. Beaches	X
	03. Sand Other Than Beaches	X
	04. Bare Exposed Rock	/
	05. Other	/
08. Tundra		/
	01. Tundra	/
09. Permanent Snow and Icefields		/
	01. Permanent Snow and Icefields	/
Note: Symbols Denote: X Proven Capability / Believed Possible 0 Not Possible ? Unknown		

Table 2 Classification Accuracy Table

Classification Table: 11:02:50

Rejection Level = 0.000000 Percent
Group Biases: Group Bias
4 0.40000

TNG Set	0	1	2	3	4	5	6	7	8
1	0.000	96.552	0.000	0.000	0.000	0.000	0.000	0.000	3.448
2	0.000	0.000	96.552	0.000	0.000	3.448	0.000	0.000	0.000
3	0.000	0.000	0.000	100.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.769	0.000	0.769	90.000	5.385	0.000	0.000	3.077
5	0.000	0.000	4.706	0.000	1.176	91.765	0.000	0.000	2.353
6	0.000	0.000	0.000	0.000	0.000	0.000	98.182	1.818	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	100.000	0.000
8	0.000	1.562	1.562	0.000	0.000	3.125	0.000	0.000	93.750

Program Run Time = 00:00:36

0 Unclassified
1 Tended Grass
2 Forest Land
3 Extractive Earth
4 Urban
5 Wetlands
6 Deep Water
7 Shallow Water
8 Rangeland (Untended Grass)

Table 3 Automatic Tabulation of Category Areas

ERTS Scene ID - 1265-15474
Date of Scene - 14APR73
Center of Scene - N43-17/W082-42
Sun Coordinates - EL49 Degrees
AZ138 Degrees
Spacecraft Heading - 191 Degrees
Tape Number - 2
Starting Scan Line = 1700
Ending Scan Line = 2340

Category	Percent of Total	Acres	Sq. Km.
Unclassified	12.17	70,747.48	286.30
Tended Grass	9.20	53,468.36	216.38
Forest Land	11.31	65,732.55	266.01
Extractive Earth	1.83	10,632.10	43.03
Urban	15.94	92,621.77	374.83
Wetlands	10.10	58,688.14	237.50
Water Deep	1.01	5,879.11	23.79
Water Shallow	0.73	4,220.16	17.08
Rangeland	37.72	219,216.36	887.14
Totals	100.00	581,206.06	2,352.06

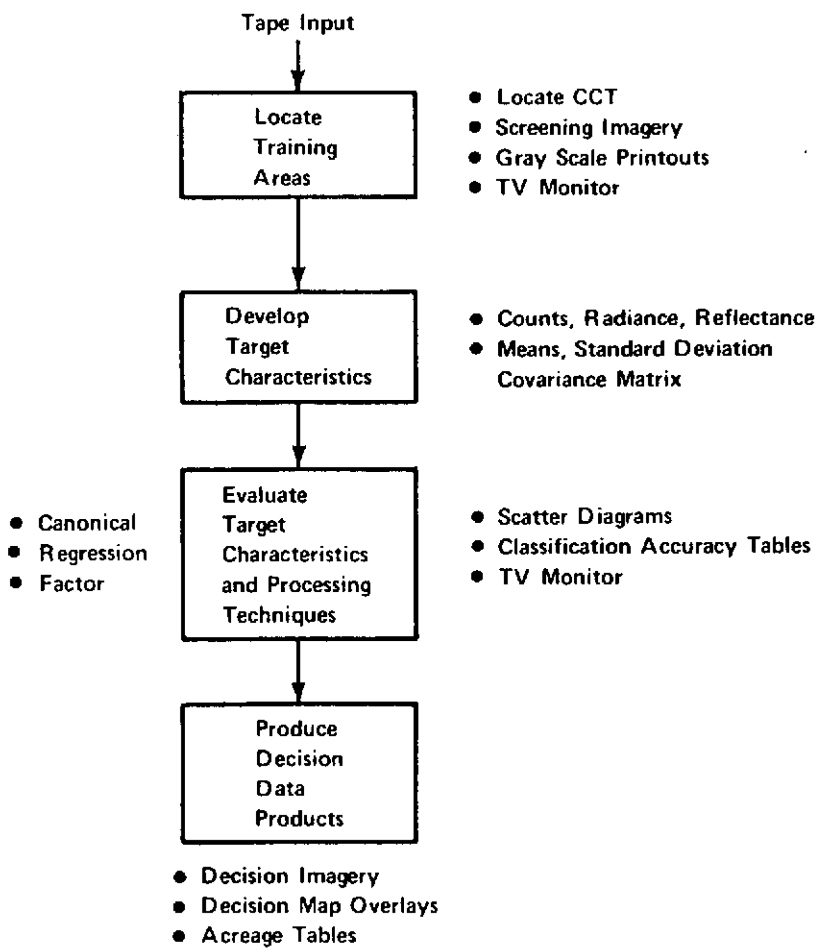
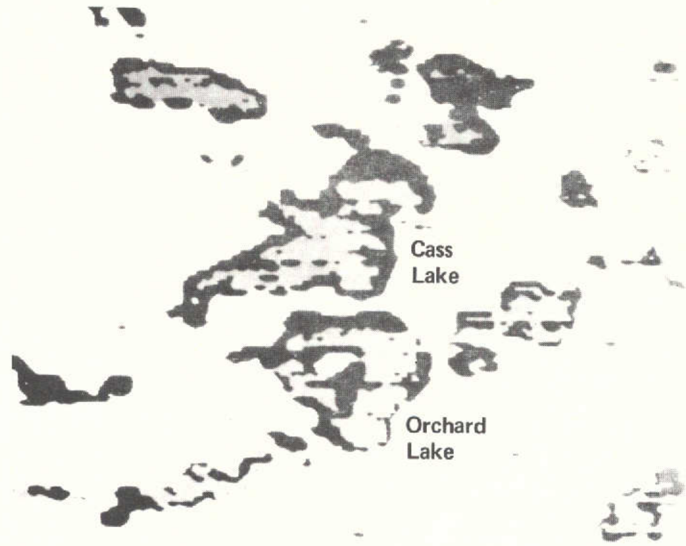


Figure 1 Computer Processing of ERTS Tapes

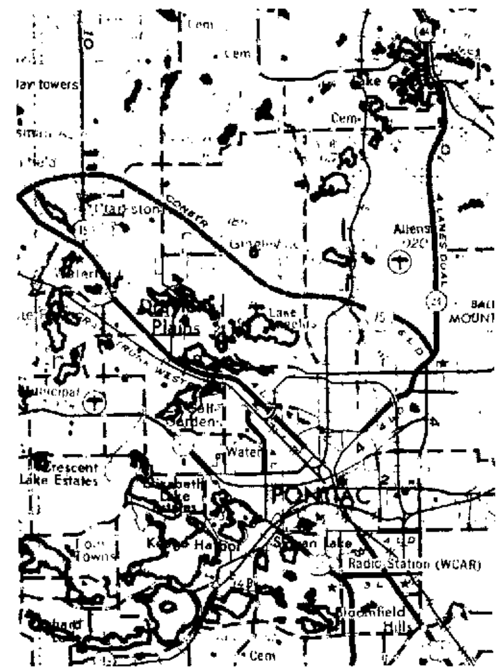
Aerial Photo-Mosaic of Portion
of Oakland County



Decision Imagery of Area in Aerial
Photograph Showing Deep (Light)
and Shallow (Dark) Water

Figure 2 Comparison of Aerial Photograph with ERTS Decision Imagery

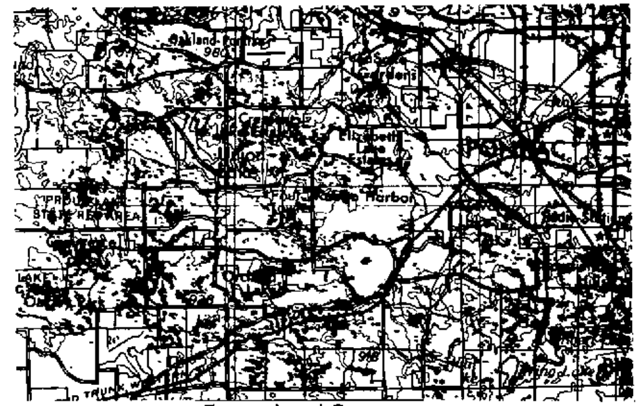
Plotter Overlay of Water Boundaries



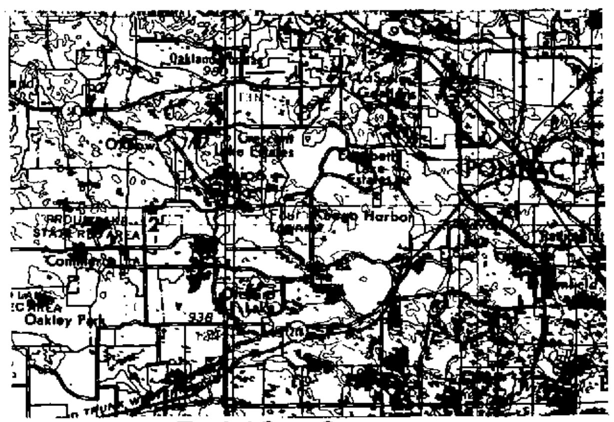
Plotter Overlay on AMS 1:250,000 Base Map

Figure 3 Computer-Generated Map of Water Boundaries from ERTS Tapes

Urban Category



Forest Land Category



Tended Grass Category

Lake Categories (Shallow and Deep Water)

Figure 4 Land-Use Categories Overlayed on AMS 1:250,000 Map